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Document Title **Calorimeter Module Assembly and Test Plan**		

Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

Calorimeter Module Assembly and Test Plan

DOCUMENT APPROVAL

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1 PURPOSE

This document specifies the plan for assembly and test of GLAST calorimeter modules.

2 DEFINITIONS

2.1 Acronyms

A&T	Assembly and Test
AFEE	Analog Front End Electronics
CAL	LAT calorimeter subsystem
CDE	Crystal Detector Element
CES	Checkout Electronics System
CPT	Comprehensive Performance Test
DAS	Data Analysis System
EGSE	Electronics Ground Support Equipment
FEE	Front End Electronics
FWHM	Full Width Half Maximum
GLAST	Gamma-ray Large Area Space Telescope
LAT	Large Area Telescope
LPT	Limited Performance Test
NRL	Naval Research Laboratory
PEM	Pre-electronics Module
PS	Power Supply
QA	Quality Assurance
SLAC	Stanford Linear Accelerator Center
TBD	To Be Determined
TBR	To Be Resolved

2.2 Definitions

γ	Gamma Ray
μsec, μs	Microsecond, 10^{-6} second
Analysis	A quantitative evaluation of a complete system and /or subsystems by review/analysis of collected data.

C	Degrees Celsius
cm	Centimeter
Demonstration	To prove or show, usually without measurement of instrumentation, that the project/product complies with requirements by observation of results.
eV	Electron Volt
Hz	Hertz – cycles per second
Inspection	To examine visually or use simple physical measurement techniques to verify conformance to specified requirements.
MeV	Million Electron Volts, 10^6 eV
mm	Millimeter
μsec, μs	Microsecond, 10^{-6} second
ph	Photons
s, sec	Seconds
Simulation	To examine through model analysis or modeling techniques to verify conformance to specified requirements.
Testing	A measurement to prove or show, usually with precision measurements or instrumentation, that the project/product complies with requirements.
Validation	Process used to assure the requirement set is complete and consistent, and that each requirement is achievable.
Verification	Process used to ensure that the selected solutions meet specified requirements and properly integrate with interfacing products.

3 APPLICABLE DOCUMENTS

Documents relevant to the Calorimeter Module Assembly and Test Plan include the following.

3.1 Design Documents

Calorimeter Module Assembly, Test, and Calibration Requirements, LAT-SS-00222.

Calorimeter Muon Telescope Requirements Specification.

Calorimeter PEM-CES Integration Procedure.

Calorimeter Electronic Calibration Procedure.

Calorimeter Performance Acceptance Standards and Tests, LAT-SS-00231.

4 Introduction

This document was developed under the following assumptions.

1. Nineteen CAL PEMs will be built in France.
2. CAL AFEE boards are tested and validated prior to integration with the PEM.
3. PEM A and B arrive at NRL on 14 February 2003 and 7 March 2003, respectively. PEM A is the Qualification Model. PEM B is the flight spare.

4. PEM 1 arrives at NRL on 2 May 2003. PEM 1 is the first of the flight units.
5. Completed CAL modules A and B must be ready for integration (RFI) at SLAC on 15 August 2003.
6. Completed CAL modules 1 and 2 must be RFI at SLAC on 3 Nov 2003.
7. Completed CAL modules 3 and 4 must be RFI at SLAC on 2 January 2004.
8. Completed CAL modules 15 and 16 must be RFI at SLAC on26 March 2004. This item and previous item imply a production delivery rate of one module approximately every week, unless deliveries begin prior to the required time.
9. Each CAL crystal will be subject to at least 12 full thermal-vac cycles during test. Four cycles are required before delivery of completed CAL module to SLAC. Any cycles completed in France on the CDEs prior to delivery of PEM to NRL are not counted in the required 12 cycles. NRL must perform the four cycles regardless of the cycles on the CDEs in France. One cycle at NRL shall be thermal-vacuum with functional test at temperature and pressure excursions.
10. This sequence includes acceptance tests for the PEMs, but it assumes that elements to be integrated with the PEMs – the AFEE boards, calorimeter Tower Electronics Modules (TEMs), and flight (TBR) power supplies – are accepted and verified separately, prior to entry into this sequence. We expect to integrate flight TEMs and deliver them to the Instrument Integration site as part of the CAL.

5 Assembly and Test Sequence

The following assembly and test sequence applies to each of the 19 CAL Modules. A flow chart of this sequence is shown in Figure 1, where it is divided into five general themes: (A) acceptance tests of the PEMs, (B) electronics integration and checkout, (C) calibration, (D) environmental tests, and (E) final verification and preparation for shipping.

1. Receipt at NRL. Comparison with shipping logs to confirm identity of items shipped. Visual inspection for shipping damage.
2. Mass Properties Measurement #1. Establishes weight and physical dimensions of PEM.
3. PEM Checkout Electronics Integration. Install PEM in PEM-CES for readout of large and small PIN diodes of each log face. Limited functional test of EGSE hardware.
4. Muon Calibration #1. Confirms quality of PIN diode bonds and generates light attenuation maps. Minimum run time = 24 hrs. Document results.
5. AFEE Integration. Attachment of CAL AFEE boards. Attachment of 192 flex cables. Inspection.
6. CAL TEM and PS Integration. Integration and simple aliveness test. Document results.
7. Comprehensive State Functional Testing #1. Establishes full functionality of integrated CAL Module. Analyze and document results.
8. Electronic Calibration. Charge injection calibration. Analyze and document results.
9. Muon Calibration #2. Establishes baseline gain of integrated system. Analyze data. Compare with PEM-CES response and known gain of AFEE. Document results.
10. Mass Properties Measurement #2. Establishes weight, center-of-mass, and physical dimensions of assembled CAL Module.
11. Thermal-Vac Testing. Four cycles over qualification or workmanship range (as appropriate for the module under test), with temporal gradient <10C per hour and holding temperature limits at least 2 hours. The plateau time shall be based on the time required to perform performance/functional tests, but shall not be less than 2 hours. Require operation and functional tests during only one cycle at the hot and cold plateau. Limited performance test following each cycle. Document results.
12. Vibration Testing. The vibration testing comprises three components: modal frequency verification, sine burst testing, and random vibration testing. Includes limited performance test. Document results.

13. Electromagnetic Compatibility Testing. Establishes electromagnetic noise production and susceptibility. Test is performed only on EM and QM models. Document results.
14. Muon Calibration #3. Establishes no degradation in performance during environmental testing and handling.
15. Comprehensive Performance Testing #2. Establishes no degradation in operation during environmental testing and handling.
16. Mass Properties Measurement #3. Establishes no change in weight, center-of-mass, and physical dimensions of assembled CAL Module during environmental testing.
17. Pre-ship Review and Sign-off. Establishes readiness for shipment.
18. Shipment to LAT Instrument Integration Site.

Details of each activity are given in the following subsections. The durations of the activities are listed for the individual PEMs or Modules. Generally, we have allowed more time for each activity for the earlier PEMs, under the assumption that with practice the procedures will move more quickly and efficiently.

5.1 Receipt at NRL

The calorimeter PEM unit will be received at NRL's A&T Cleanroom. The components will be removed from their shipping containers and inspected by NRL Quality Assurance personnel for item identification against the Cert log and other shipping papers. A visual inspection will be made to ascertain the condition of the hardware and to note any visual abnormalities. Receipt status and comments will be entered into the CAL Module Properties Database. The PEM will be integrated with its Transportation Cart. The hardware will then be released to the A&T Manager for immediate Mass Properties Measurement. If scheduling does not permit immediate Mass Properties Measurement, the hardware will be placed in secure dry storage.

The duration and personnel required for this task are listed below for each PEM.

PEM	Duration (days)	Personnel
EM	2	2 Scientists, 2 Technicians
A, B, 1, 2	1	1 Scientist, 2 Technicians
3 – 6	1	2 Technicians
7 – 16	0.5	2 Technicians

5.2 Mass Properties Measurement #1

The calorimeter PEM will be weighed and its physical dimensions will be measured. The precision of the mass measurement will be to the nearest gram. The precision of the dimensional measurements will be to the nearest 0.1 mm (TBR). The PEM will be removed from its Transportation Cart as required, but for safety of the PEM, the Cart will be available at all times. A Technician will confirm that the measured mass and dimensions comply with the relevant requirements. Measurements and compliance will be entered into the CAL Module Properties Database.

Dimensional measurements will be made with TBD hardware. Mass measurements will be made with TBD hardware.

The duration and personnel required for this task are listed below for each PEM.

PEM	Duration (days)	Personnel
EM	2	2 Scientists, 2 Technicians
A, B, 1, 2	1	1 Scientist, 2 Technicians
3 – 6	1	2 Technicians
7 – 16	0.5	2 Technicians

5.3 PEM Checkout Electronics Integration

The PEM will be integrated with the PEM Checkout Electronics System (PEM-CES) following the detailed instructions in the CAL PEM-CES Integration Procedure, LAT-TBD. The PEM-CES provides simultaneous, 384-channel readout of all PIN photodiodes, along with additional channels for the Muon Telescope. After integration, the electronics Technician and data Technician will perform functional tests to establish that all channels are alive, being properly digitized, and logged to disk.

The duration and personnel required for this task are listed below for each PEM.

PEM	Duration (days)	Personnel
EM	5	2 Scientists, 1 Engineer, 2 Technicians
A, B, 1, 2	3	1 Scientist, 1 Engineer, 2 Technicians
3 – 6	3	1 Engineer, 2 Technicians
7 – 16	2	1 Engineer, 1 Technician

5.4 Muon Calibration #1

The PEM-CES will be integrated with the Muon Telescope (MuTel) for initial muon calibration. A Technician will perform a functional test of not less than one 30-minute accumulation of muon data to ensure that each PIN photodiode is registering a muon peak within the digitizable signal range. The functional test data will be analyzed by PEM EGSE software, and the functional test results will be logged into the CAL Module Properties Database. Following a successful functional test, the Technician will begin a long muon data accumulation. This run shall last at least 24 hours (TBR). Following the run, the data will be analyzed by PEM EGSE software to derive scintillation light yields and light tapering response maps. The relative light yields and light-tapering functions from the muon calibration will be compared to pre-ship calibration performed in France. Results of this run and comparison will be logged in the CAL Module Properties Database. Raw calibration data will be archived to a long-term storage medium. Following the calibration, the PEM-CES will be disintegrated from the MuTel and integrated with Rotation Mount.

Acquire data over night to log ~150 good muons per cm^2 in each CsI crystal. Requires muon hodoscope with rms position resolution ~3 mm or less. Minimum run time = 24 hrs. Analyze data to confirm good diode bonds and sensible response maps. This is the best opportunity to map the crystal response as a function of position.

The duration and personnel required for this task are listed below for each PEM.

PEM	Duration (days)	Personnel
EM	5	2 Scientists, 2 Technicians
A, B, 1, 2	4	1 Scientist, 2 Technicians
3 – 6	3	1 Scientist, 2 Technicians
7 – 16	2	1 Scientist, 1 Technician

5.5 AFEE Integration

The PEM will be disintegrated from the Checkout Electronics System and attached to the Rotation Mount. The four Front End Electronics boards will be mechanically attached, and the 192 Kapton flex cables attached to the Front End boards. As each board is integrated, Kapton attachments will be inspected by a QA technician, and a simple power-up aliveness test will be performed. Following integration, the Module will be returned to its Transportation Cart.

During integration of PEMs EM, A, B, 1, and 2, aliveness and simple functional testing and inspection will be performed after each of the AFEE boards is attached. For later PEMs, this testing will occur only after all four boards are integrated. Tests are performed using laboratory power supplies and a basic TEM simulator.

The integrated PEM and AFEE form a completed CAL Module.

The duration and personnel required for this task are listed below for each PEM.

PEM	Duration (days)	Personnel

EM	15	1 Scientist, 1 Engineer, 2 Technicians
A, B, 1, 2	8	1 Scientist, 1 Engineer, 2 Technicians
3 – 6	6	1 Engineer, 2 Technicians
7 – 16	6	1 Engineer, 1 Technician

5.6 CAL TEM and PS Integration

The CAL Module will be integrated with its flight Tower Electronics Module (TEM) and its flight (TBR) power supply (PS). A power-up and aliveness functional test will be performed on the integrated Module and TEM.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	5	1 Scientist, 1 Engineer, 2 Technicians
A, B, 1, 2	2	1 Scientist, 1 Engineer, 2 Technicians
3 – 6	1	1 Engineer, 1 Technician
7 – 16	1	1 Engineer, 1 Technician

5.7 Comprehensive State Functional Testing

The CAL Module and TEM will be subject to comprehensive performance and functional testing to confirm compliance with operating and performance requirements as an integrated whole. Comprehensive Performance Tests (CPT) are detailed functional tests conducted under conditions of varying internal and external parameters with emphasis on all possible modes of operation for the Module and TEM. Portions of the CPT repeat elements of the AFEE checkout tests. Functionality will be compared with AFEE checkout to confirm no loss of performance. Test results and performance summary will be logged to the CAL Module Properties Database.

For each Module, one data Technician and one Scientist will be assigned to this task for one day.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	5	2 Scientist, 1 Engineer, 2 Technicians
A, B, 1, 2	4	2 Scientist, 1 Engineer, 2 Technicians
3 – 6	3	1 Scientist, 1 Engineer, 1 Technician
7 – 16	2	1 Scientist, 1 Engineer, 1 Technician

5.8 Electronic Calibration

The CAL Module and Controller will be calibrated following the Electronic Calibration Procedure (LAT-TBD). This is a charge-injection calibration of each of the 384 analog and digital electronics channels. Charge is injected into each analog front end at a repetition rate of 100 Hz covering the full dynamic range of the electronics. Data will be logged to the DAS and analyzed with EGSE software. Raw calibration data will be archived to a long-term storage medium. The primary output of this test is a set of 384 electronic gain calibration curves. Test results and performance summary will be logged to the CAL Module Properties Database.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	5	1 Scientist, 1 Engineer, 2 Technicians
A, B, 1, 2	2	1 Scientist, 2 Technicians
3 – 6	2	1 Scientist, 1 Technician

7 – 16	1	1 Scientist, 1 Technician

5.9 Muon Calibration #3

The CAL Module will be integrated with the Muon Telescope (MuTel) for a second muon calibration. A Technician will perform a functional test of not less than one 30-minute accumulation of muon data to ensure that each PIN photodiode is registering a muon peak. The functional test data will be analyzed by Module EGSE software, and the functional test results will be logged into the CAL Module Properties Database. Following a successful functional test, the Technician will begin a long muon data accumulation. This run shall last at least 24 hours (TBR). Following the run, the data will be analyzed by Module EGSE software to derive scintillation light yields and light tapering response maps. The relative light yields and light-tapering functions from the muon calibration will be compared to PEM-CES response and the known gain of the FEE to confirm expected change in instrument performance. This calibration establishes the baseline gain of the integrated system. Results of this run and comparison will be logged in the CAL Module Properties Database. Raw calibration data will be archived to a long-term storage medium. Following the calibration, the Module will be disintegrated from the MuTel and reintegrated with its Transportation Cart.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	5	2 Scientists, 2 Technicians
A, B, 1, 2	3	1 Scientist, 2 Technicians
3 – 6	2	1 Scientist, 2 Technicians
7 – 16	2	1 Scientist, 2 Technicians

5.10 Mass Properties Measurement #2

The completed CAL Module will be weighed, its center of mass determined, and its physical dimensions will be measured. The precision of the mass measurement will be to the nearest gram. The precision of the dimensional measurements will be to the nearest 0.1 mm (TBR). The Module will be removed from its Transportation Cart as required, but for safety of the Module, the Cart will be available at all times. A Technician will confirm that the measured mass and dimensions comply with the relevant requirements. Measurements and compliance will be entered into the CAL Module Properties Database.

Dimensional measurements will be made with TBD hardware. Mass measurements will be made with TBD hardware.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	2	2 Scientists, 2 Technicians
A, B, 1, 2	1	1 Scientist, 2 Technicians
3 – 6	1	2 Technicians
7 – 16	0.5	2 Technicians

5.11 Thermal-Vac Functional Testing

The CAL Module and TEM will be subjected to four thermal-vacuum cycles over a wide temperature range with a temperature gradient of <10C per hour. The plateau time will be based on the time required to perform Limited Performance Testing but will not be less than two hours. The temperature range shall cover a broader range for the EM, A, and B Modules, and a narrower workmanship range for Modules 1–16. The temperature and pressure ranges and the duration of the test will comply with the requirements specified in LAT-TBD, which is the document of final authority on these tests. The Module will be powered during one of these thermal-vac cycles: Limited Performance Tests will be performed at the hot and cold temperature plateau. Measured temperature profiles and test results will be logged in the CAL Module Properties Database. Limited Performance Tests (LPT) will be performed at the completion of the cycling to ensure no degradation in operation.

Special consideration must be given to prevent hydration and/or condensation during all setup and test operations. All cold cycles will be performed in a dry environment. Sufficient time (TBD) to ensure return to ambient temperature for all portions of the Module must be allowed. To prevent water condensation, a cold Module must not be exposed to ambient air.

The fastest possible cycle time is approximately 5 hrs to cold + 2 hrs at cold + 8 hrs to hot + 2 hrs to cold + 3 hrs to ambient = 20 hrs.

These thermal-vacuum cycles will be performed with NRL's Thermal-Vacuum Facility.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	15	2 Scientists, 2 Technicians, TV facility operators
A, B, 1, 2	10	1 Scientist, 2 Technicians, TV facility operators
3 – 6	8	1 Scientist, 2 Technicians, TV facility operators
7 – 16	8	1 Scientist, 2 Technicians, TV facility operators

5.12 Vibration Testing

The CAL Module will be subjected to vibration testing to verify its compliance with its mechanical design parameters and to demonstrate its robustness against the launch vibration environment. The vibration testing shall comprise three subsets: minimum modal frequency verification, sine-burst strength testing, and random vibration testing. Test vibration levels and requirements are given in LAT-TBD. Measured resonance and vibration profiles and test results will be logged in the CAL Module Properties Database. LPT will be performed at the completion of vibration testing to establish no degradation of performance.

These vibration tests will be performed at NRL's Vibration Test Facility.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	10	2 Scientists, 2 Technicians, Vibe facility operators
A, B, 1, 2	5	1 Scientist, 2 Technicians, Vibe facility operators
3 – 6	3	1 Scientist, 2 Technicians, Vibe facility operators
7 – 16	3	1 Scientist, 2 Technicians, Vibe facility operators

5.13 EMC/EMI Testing

The Engineering Model and Qualification Model (Modules EM and A) will be subjected to electromagnetic compatibility (EMC) testing to ensure that it will neither be a source of electromagnetic interference (EMI) nor be susceptible to EMI when integrated with other components of the LAT. EMC/EMI testing of the 16 flight CAL Modules and the flight spare is not required: verification of compliance with EMC/EMI requirements will be by assessment of similarity with the QM. LPT will be performed at the completion of EMC/EMI testing.

The EMC/EMI tests will be performed at NRL's EMC/EMI Test Facility.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	3	1 Scientist, 1 Engineer, 1 Technician, EMC/EMI facility operators
A, B	2	1 Scientist, 1 Engineer, 1 Technician, EMC/EMI facility operators
1 – 16	0	

5.14 Muon Calibration #3

The CAL Module will be integrated with the Muon Telescope (MuTel) for a third muon calibration. A Technician will perform a functional test of not less than one 30-minute accumulation of muon data to ensure that each PIN photodiode is registering a muon peak. The functional test data will be analyzed by Module EGSE software, and the functional test results will be logged into the CAL Module Properties Database. Following a successful functional test, the Technician will begin a long muon data accumulation. This run shall last at least 24 hours (TBR). Following the run, the data will be analyzed by Module EGSE software to derive scintillation light yields and light tapering response maps. The relative light yields and light-tapering functions from the muon calibration will be compared to the pre-thermal-vac and pre-vibration response to confirm no change in instrument performance. Results of this run and comparison will be logged in the CAL Module Properties Database. Raw calibration data will be archived to a long-term storage medium. Following the calibration, the Module will be disintegrated from the MuTel and reintegrated with its Transportation Cart.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	3	2 Scientists, 2 Technicians
A, B, 1, 2	2	1 Scientist, 2 Technicians
3 – 6	2	1 Scientist, 2 Technicians
7 – 16	2	1 Scientist, 2 Technicians

5.15 Comprehensive State Functional Testing #2

The CAL Module and TEM will be subjected to comprehensive performance and functional testing to confirm no degradation of operating and performance requirements during environmental testing. This test will repeat the Comprehensive State Performance Testing #1, although some tests will be abbreviated. Performance will be compared with CPT #1 to confirm no degradation. Test results and performance summary will be logged to the CAL Module Properties Database.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	5	2 Scientist, 1 Engineer, 2 Technicians
A, B, 1, 2	3	2 Scientist, 1 Engineer, 2 Technicians
3 – 6	2	1 Scientist, 1 Engineer, 1 Technician
7 – 16	2	1 Scientist, 1 Engineer, 1 Technician

5.16 Mass Properties Measurement #3

The assembled CAL Module, TEM, and PS (TBR) will be weighed, its center of mass determined, and its physical dimensions will be measured for comparison with measurements made prior to environmental testing. The precision of the mass measurement will be to the nearest gram. The precision of the dimensional measurements will be to the nearest 0.1 mm (TBR). The Module will be removed from its Transportation Cart as required, but for safety of the Module, the Cart will be available at all times. A Technician will confirm that the measured mass and dimensions comply with the relevant requirements. Measurements, deviations, and compliance will be entered into the CAL Module Properties Database.

Dimensional measurements will be made with TBD hardware. Mass measurements will be made with TBD hardware.

The duration and personnel required for this task are listed below for each Module.

Module	Duration (days)	Personnel
EM	2	2 Scientists, 2 Technicians
A, B, 1, 2	1	1 Scientist, 2 Technicians

3 – 6	1	2 Technicians
7 – 16	0.5	2 Technicians

5.17 Pre-ship Review and Sign-off

The CAL Module and TEM are installed in the Dry Storage and Shipping Fixture. Test Reports and associated resolution reports are assembled for presentation to the Pre-Ship Review Board. The status of all discrepancies, functional anomalies, subsystem failure-free operating hours, and out-of-tolerance levels detected during the Assembly and Test process will be presented to the Board. This review will contain all items written against the Module and the associated GSE. The disposition of all reports and actions will be included or attached to a summary report, which will accompany the Module during Instrument I&T. The Module and TEM must satisfy the requirements specified in Calorimeter Performance Acceptance Standards and Tests (LAT-SS-00231).

The EM Module is not subject to a Pre-Ship Review.

The duration and personnel required for this task are listed below for each Module.

Module	**Duration (days)**	**Personnel**
EM	0	
A, B, 1, 2	1	Pre-Ship Review Board
3 – 6	1	Pre-Ship Review Board
7 – 16	1	Pre-Ship Review Board

5.18 Shipment to Instrument Integration Site

The completed CAL Module and TEM are shipped to SLAC for integration into the LAT. The EM Module is not shipped to the integration site, rather it used for hadronic beam tests (see LAT-TBD).

Figure 1. Calorimeter Module Assembly and Test Flow